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(54) **SEMICONDUCTOR STRUCTURE
EXHIBITING REDUCED LEAKAGE
CURRENT AND METHOD OF FABRICATING
SAME**

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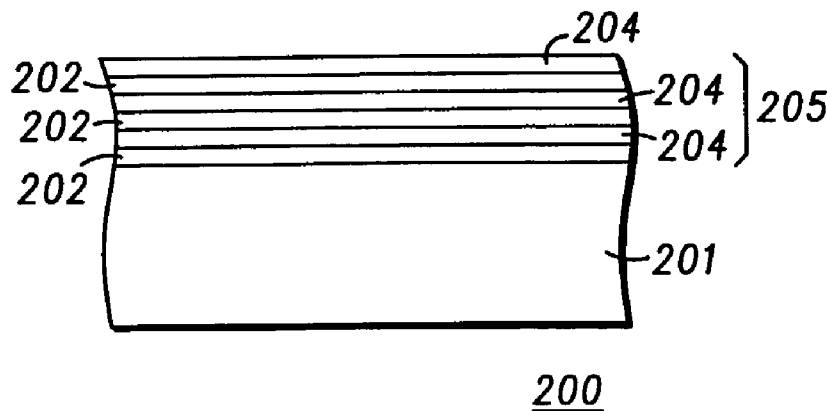
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(57) **ABSTRACT**

A semiconductor structure exhibiting reduced leakage current is formed of a monocrystalline substrate (101) and a strained-layer heterostructure (105). The strained-layer heterostructure has a first layer (102) formed of a first monocrystalline oxide material having a first lattice constant and a second layer (104) formed of a second monocrystalline oxide material overlying the first layer and having a second lattice constant. The second lattice constant is different from the first lattice constant. The second layer creates strain within the oxide material layers, at the interface between the first and second oxide material layers of the heterostructure, and at the interface of the substrate and the first layer, which changes the energy band offset at the interface of the substrate and the first layer.

11 Claims, 1 Drawing Sheet



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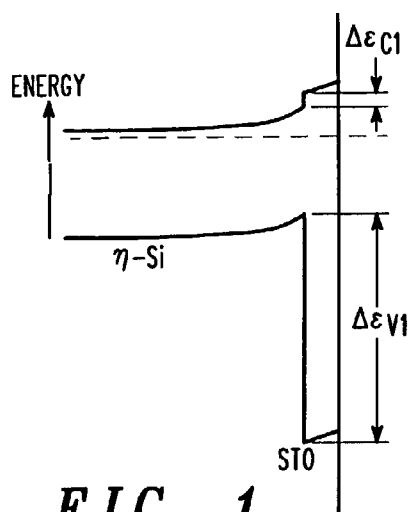


FIG. 1

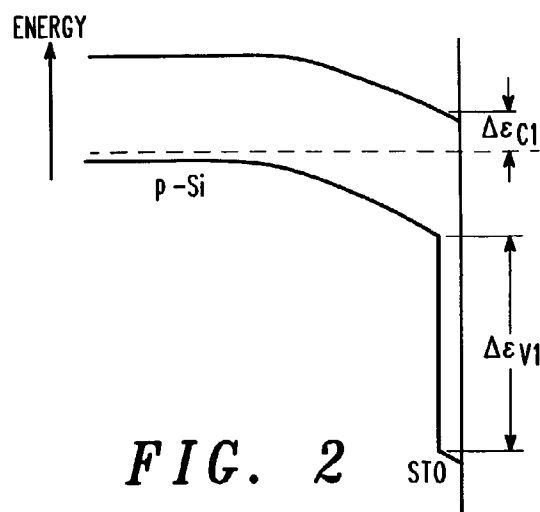


FIG. 2

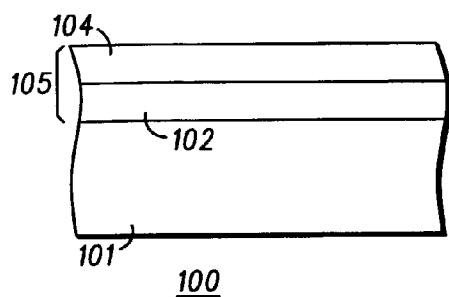


FIG. 3

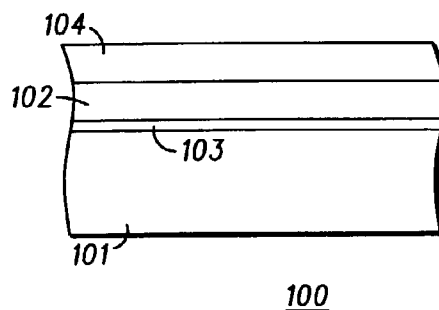


FIG. 4

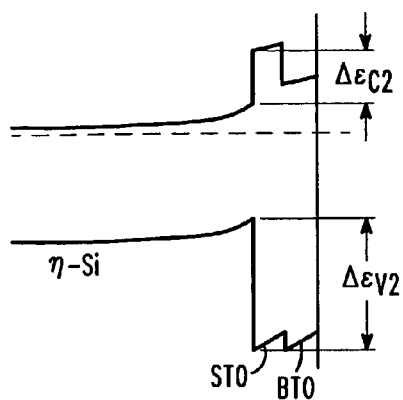


FIG. 5

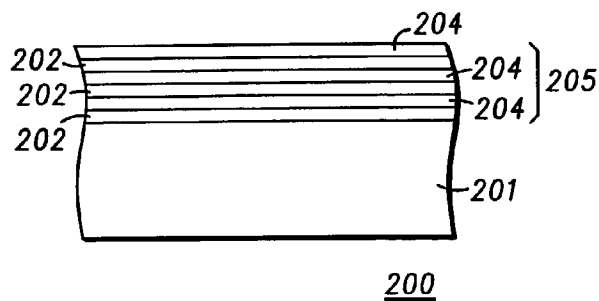


FIG. 6

1

**SEMICONDUCTOR STRUCTURE
EXHIBITING REDUCED LEAKAGE
CURRENT AND METHOD OF FABRICATING
SAME**

FIELD OF THE INVENTION

This invention relates generally to semiconductor structures and devices and to a method for their fabrication, and more specifically to fabrication of semiconductor structures, devices, and integrated circuits that include an epitaxially grown, high dielectric constant strained-layer heterostructure to reduce leakage current.

BACKGROUND OF THE INVENTION

The search for alternative gate oxide materials has become more vigorous as complementary metal-oxide-semiconductor (CMOS) technology using SiO_2 as the gate oxide approaches its fundamental limits. Currently, it is not possible to use SiO_2 layers on Si at the thickness required to achieve the next desired level of performance (approximately 10 angstroms) without unacceptably high gate leakage current. Utilizing oxides with dielectric constants greater than that of SiO_2 permits larger gate oxide thickness with the same capacitance. However, in addition to a high dielectric constant, the high dielectric constant oxide should exhibit sufficiently large energy band offsets at the interface with Si so that Schottky leakage current is negligible.

Several oxides have been investigated as potential candidates to replace SiO_2 . One of the most promising thus far is perovskite oxides, such as SrTiO_3 ("STO"). These oxides have a high bulk dielectric constant and exhibit a high degree of structural compatibility with Si, making epitaxy possible. It has been demonstrated that single-crystal SrTiO_3 thin films can be grown on $\text{Si}(001)$ substrates by molecular beam epitaxy (MBE) with interface state densities as low as 6×10^{10} states/cm². See, e.g., R. A. McKee et al, *Phys. Rev. Lett.* 81, p. 3014 (1998) and K. Eisenbeiser et al., *Appl. Phys. Lett.* 76, p. 1324 (2000). The equivalent dielectric layer thickness of SrTiO_3 may be more than ten times less than that of SiO_2 . Thus, the gate oxide layer thickness can be ten times larger when SiO_2 is replaced with SrTiO_3 , and yet the capacitance can be approximately the same.

Although the SrTiO_3/Si structure demonstrates these promising properties, theoretical and experimental evidence indicates that the structure may exhibit significant Schottky electron leakage current. See, e.g., J. Robertson and C. W. Chen, *Appl. Phys. Lett.* 74, p. 1168 (1999) and S. A. Chambers et al., *Appl. Phys. Lett.* 77, p. 1662 (2000), herein incorporated by reference. Referring to FIGS. 1 and 2, the SrTiO_3/Si structure exhibits a much smaller conduction band offset (ΔE_{c1}) compared to the valence band offset (ΔE_{v1}) for both n-Si and p-Si structures and, hence, almost the entire band discontinuity resides at the valence band edge. Accordingly, Schottky leakage current may result. It would be desirable to engineer the energy band offset such that appropriate height Schottky barriers exist at both conduction and valence band edges.

Accordingly, a need exists for a semiconductor structure having a gate oxide formed of a high dielectric constant which exhibits low Schottky electron leakage current.

In addition, a need exists for a method of changing the energy band offset at the interface of two crystalline materials to reduce Schottky leakage current.

A need further exists for a method of changing the energy band offset at the interface of two crystalline materials to accommodate specific device applications.

2

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the accompanying figures, in which like references indicate similar elements, and in which:

FIG. 1 is a graphical representation of an energy band diagram of a $\text{SrTiO}_3/\text{n-Si}$ structure;

FIG. 2 is a graphical representation of an energy band diagram of a $\text{SrTiO}_3/\text{p-Si}$ structure;

FIGS. 3 and 4 illustrate schematically, in cross section, device structures in accordance with various embodiments of the invention;

FIG. 5 is a graphical representation of an energy band diagram of a device structure in accordance with an embodiment of the invention; and

FIG. 6 illustrates schematically, in cross section, a device structure in accordance with another embodiment of the invention.

Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

The present invention provides a method of fabricating a high dielectric constant crystalline oxide layer on a semiconductor substrate using a crystalline high dielectric constant strained-layer heterostructure. In one aspect of the invention, the strained-layer heterostructure is formed of a first high dielectric constant crystalline oxide layer underlying a second crystalline oxide layer which has a lattice constant different from the first. The difference in lattice constants between the two layers may create strain within the oxide layers of the heterostructure, at the interface between the oxide layers of the heterostructure and at the interface of the substrate and the heterostructure which result in creation of a suitable Schottky barrier at the semiconductor substrate/heterostructure interface.

FIG. 3 illustrates schematically, in cross section, a structure 100 in accordance with an exemplary embodiment of the present invention. Structure 100 may be a device such as, for example, a component of a MOS device or any high dielectric constant device. Structure 100 includes a substrate 101, which may be formed of a monocrystalline semiconductor material, such as, for example, silicon (Si), strontium-passivated Si, germanium (Ge), silicon germanium (Si—Ge), indium phosphide (InP), or gallium arsenide (GaAs). Substrate 101 may also comprise a suitable compound semiconductor material, such as, for example, indium gallium arsenide (InGaAs), indium aluminum arsenide (InAlAs), aluminum gallium arsenide (AlGaAs), indium gallium phosphide (InGaP), and other compound semiconductor materials known to those skilled in the art to be suitable for particular semiconductor device applications. In one embodiment, substrate 101 comprises a monocrystalline n-type silicon substrate. Substrate 101 may optionally include a plurality of material layers such that the composite substrate may be tailored to the quality, performance, and manufacturing requirements of a variety of semiconductor device applications.

In another embodiment of the invention, substrate 101 may comprise a (001) Group IV material that has been off-cut towards a (110) direction. The growth of materials on a miscut Si (001) substrate is known in the art. For example, U.S. Pat. No. 6,039,803, issued to Fitzgerald et al. on Mar. 21, 2000, which patent is herein incorporated by reference, is directed to growth of silicon-germanium and germanium

layers on miscut Si (001) substrates. Substrate **101** may be off-cut in the range of from about 2 degrees to about 6 degrees towards the (110) direction. A miscut Group IV substrate reduces dislocations and results in improved quality of a subsequently grown monocrystalline material layers.

A monocrystalline oxide interface layer **102** is formed overlying substrate **101**. Monocrystalline oxide interface layer **102** may comprise a monocrystalline oxide material selected for its crystalline (i.e., lattice) compatibility with the underlying substrate. For example, the material could be an oxide or nitride having a lattice structure closely matched to the substrate. Materials that are suitable for the monocrystalline oxide interface layer **102** include metal oxides such as the alkaline earth metal titanates, alkaline earth metal zirconates, alkaline earth metal hafnates, alkaline earth metal tantalates, alkaline earth metal ruthenates, alkaline earth metal niobates, alkaline earth metal vanadates, perovskite oxides such as alkaline earth metal tin-based perovskites, lanthanum aluminate, lanthanum scandium oxide and gadolinium oxide. In an exemplary embodiment, layer **102** may comprise an alkaline earth metal titanate, such as, for example, barium titanate (BaTiO_3), strontium titanate (SrTiO_3), or barium strontium titanate ($\text{Sr}_z\text{Ba}_{1-z}\text{TiO}_3$), or another suitable oxide material having a thickness of up to about 100 angstroms. Preferably, monocrystalline oxide interface layer **102** is formed of SrTiO_3 having a thickness in the range of approximately 1–5 nm.

In accordance with another embodiment of the invention, as shown in FIG. 4, structure **100** may also include an amorphous intermediate layer **103** positioned between substrate **101** and monocrystalline oxide interface layer **102**. In accordance with one embodiment of the invention, amorphous intermediate layer **103** is grown on substrate **101** at the interface between substrate **101** and the growing monocrystalline oxide interface layer **102** by the controlled oxidation of substrate **101** during the growth of layer **102**. The amorphous intermediate layer typically does not affect the band discontinuity at the interface of the substrate **101** layer and the monocrystalline oxide interface layer **102**.

Referring again to FIG. 3, a monocrystalline oxide straining layer **104** is formed overlying monocrystalline oxide interface layer **102** to form a strained-layer heterostructure **105**. Layer **104** may have a thickness of from approximately one monolayer up to about 100 angstroms. Monocrystalline oxide straining layer **104** may be formed of any of those compounds previously described with reference to layer **102** in FIGS. 3 and 4 and having a crystalline lattice constant that is different than the lattice constant of layer **102**. As used herein, lattice constant refers to the distance between atoms of a unit cell measured in the plane of a surface. For example, if monocrystalline oxide interface layer **102** is formed of $\text{Sr}_x\text{Ba}_{1-x}\text{TiO}_3$ where $0 \leq x \leq 1$, monocrystalline oxide straining layer **104** may comprise $\text{Sr}_y\text{Ba}_{1-y}\text{TiO}_3$, where y does not equal x , which has a different lattice constant than $\text{Sr}_x\text{Ba}_{1-x}\text{TiO}_3$. The difference in lattice constants results in strain within layers **102** and **104**, at the interface between layers **102** and **104**, and at the interface of substrate **101** and heterostructure **105**. The strain results in an increase of the conduction band offset at the interface of substrate **101** and monocrystalline oxide interface layer **102**, effecting an increase of the Schottky barrier at the interface. The strain also results in a change of the valence band offset at the interface. Preferably, if layer **102** is formed of SrTiO_3 , layer **104** is formed of BaTiO_3 having a thickness in the range of from 1 to 5 nm.

The following example illustrates a process, in accordance with one embodiment of the invention, for fabricating a semiconductor structure having a low leakage current density.

The process starts by providing a monocrystalline semiconductor substrate comprising, for example, silicon and/or germanium. In accordance with one embodiment of the invention, the semiconductor substrate is a Sr-passivated silicon wafer having a (001) orientation. The substrate is preferably oriented on axis or, at most, about 2° to about 6° off axis. At least a portion of the semiconductor substrate has a bare surface although other portions of the substrate may encompass other structures. The term “bare” in this context means that the surface in the portion of the substrate has been cleaned to remove any oxides, contaminants, or other foreign material. As is well known, bare silicon is highly reactive and readily forms a native oxide. The term “bare” is intended to encompass such a native oxide. A thin silicon oxide may also be intentionally grown on the semiconductor substrate, although such a grown oxide is not essential to the process in accordance with the invention. To epitaxially grow a monocrystalline oxide layer overlying the monocrystalline substrate, the native oxide layer must first be removed to expose the crystalline structure of the underlying substrate. The following process is preferably carried out by molecular beam epitaxy (MBE), although other epitaxial processes may also be used in accordance with the present invention. The native oxide can be removed by first thermally depositing a thin layer of strontium, barium, or combination of strontium and barium or other alkali earth metals or combinations of alkali earth metals in an MBE apparatus. In the case where strontium is used, the substrate is then heated to a temperature of about 750°C . to cause the strontium to react with the native silicon oxide layer. The strontium serves to reduce the silicon oxide to leave a silicon oxide-free surface. The resultant surface exhibits an ordered 2×1 structure. If an ordered 2×1 structure has not been achieved at this stage of the process, the structure may be exposed to additional strontium until an ordered 2×1 structure is obtained. The ordered 2×1 structure forms a template for the ordered growth of an overlying layer of a monocrystalline oxide. The template provides the necessary chemical and physical properties to nucleate the crystalline growth of an overlying layer.

In accordance with an alternate embodiment of the invention, the native silicon oxide can be converted and the substrate surface can be prepared for the growth of a monocrystalline oxide layer by depositing an alkaline earth metal oxide, such a strontium oxide, strontium barium oxide, or barium oxide, onto the substrate surface by MBE at a low temperature and by subsequently heating the structure to a temperature of about 750°C . At this temperature a solid state reaction takes place between the strontium oxide and the native silicon oxide causing the reduction of the native silicon oxide and leaving an ordered 2×1 structure with strontium, oxygen, and silicon remaining on the substrate surface. Again, this forms a template for the subsequent growth of an ordered monocrystalline oxide layer.

Following the removal of the silicon oxide from the surface of the substrate, in accordance with one embodiment of the invention, the substrate is cooled to a temperature in the range of about 200 – 800°C . and a thin layer of strontium titanate is grown on the template layer by molecular beam epitaxy. The MBE process is initiated by opening shutters in the MBE apparatus to expose strontium, titanium and oxygen sources. The ratio of strontium and titanium is approximately 1:1. The partial pressure of oxygen is initially set a minimum value to grow stoichiometric strontium titanate at a growth rate of about 0.3–0.5 nm per minute. After initiating growth of the strontium titanate, the partial pressure of oxygen is increased above the initial minimum value. The partial pressure of oxygen may cause the growth of an amorphous silicon oxide layer at the interface between the underlying substrate and the growing strontium titanate

layer. The growth of the silicon oxide layer results from the diffusion of oxygen through the growing strontium titanate layer to the interface where the oxygen reacts with silicon at the surface of the underlying substrate. The thickness of the amorphous silicon oxide layer can be controlled by varying the temperature of the process and the oxygen partial pressure. The thickness of the amorphous silicon oxide layer may be as thick as 1 nm but is preferably within the range of about 0.2 nm to about 0.7 nm. The strontium titanate grows as an ordered monocrystal with the crystalline orientation rotated by 45° with respect to the unit cell of the underlying substrate.

After the strontium titanate layer has been grown to the desired thickness, preferably from a few monolayers up to approximately 100 angstroms, a thin layer of barium titanate is grown overlying the strontium titanate layer by molecular beam epitaxy. The barium titanate layer is preferably grown to a thickness of from about a few monolayers to about 100 angstroms.

The process described above illustrates a process for forming a semiconductor structure including a silicon substrate and an overlying strained-layer heterostructure by the process of molecular beam epitaxy. The process can also be carried out by the process of chemical vapor deposition (CVD), metal organic chemical vapor deposition (MOCVD), migration enhanced epitaxy (MEE), atomic layer epitaxy (ALE), physical vapor deposition (PVD), chemical solution deposition (CSD), pulsed laser deposition (PLD), or the like. Further, by a similar process, other monocrystalline layers such as alkaline earth metal titanates, zirconates, hafnates, tantalates, vanadates, ruthenates, and niobates, perovskite oxides such as alkaline earth metal tin-based perovskite, lanthanum aluminate, lanthanum scandium oxide, and gadolinium oxide can also be grown.

An illustration of an energy band diagram of an exemplary embodiment of structure **100** wherein substrate **101** is formed of n-Si, monocrystalline oxide transition layer **102** is formed of SrTiO₃ (STO) and monocrystalline oxide straining layer **104** is formed BaTiO₃ (BTO) is shown in FIG. 5. As illustrated, the conduction band offset at the Si/STO interface (ΔE_{c2}) of structure **100** is greater than the conduction band offset at the Si/STO interface of the structure illustrated in FIG. 1, that is, $\Delta E_{c2} > \Delta E_{c1}$. Similarly, the valence band (ΔE_{v2}) offset at the Si/STO interface of structure **100** is smaller than the valence band offset at the Si/STO interface of the structure illustrated in FIG. 1, that is, $\Delta E_{v2} < \Delta E_{v1}$.

EXAMPLE

In this example, a monocrystalline semiconductor substrate of n-silicon having a (001) orientation was provided. Native oxide was removed by first thermally depositing a thin layer of strontium in an MBE apparatus. The substrate was heated to a temperature of about 750° C. to cause the strontium to react with the native silicon oxide layer. The resultant surface exhibited an ordered 2×1 structure.

Following the removal of the silicon oxide from the surface of the substrate, the substrate was cooled to a temperature in the range of about 200–800° C. and a thin layer of approximately 2 nm of strontium titanate was grown on the template layer by MBE. The MBE process was initiated by opening shutters in the MBE apparatus to expose strontium, titanium and oxygen sources. The ratio of strontium and titanium was approximately 1:1.

After the strontium titanate layer was grown on the substrate, a thin layer of approximately 2 nm of barium titanate was deposited on the strontium titanate layer using MBE at a temperature in the range of 200–800° C. Depo-

sition of the barium titanate layer formed a BTO/STO strained-layer heterostructure on Si.

The BTO/STO/Si structure was then measured using x-ray photoemission spectroscopy (XPS). XPS results from the BTO/STO/Si structure were compared to those of an STO/Si structure. The results showed an expansion of the conduction band offset at the Si/STO interface (ΔE_c) from approximately 0.01 eV for the STO/Si structure to 0.9 eV for the BTO/STO/Si structure. The valence band offset at the Si/STO interface (ΔE_v) showed a shift from –2.12 eV for the STO/Si structure to –1.27 eV for the BTO/STO/Si structure. The more balanced bandgap of the BTO/STO/Si indicates that this structure would exhibit decreased Schottky leakage current compared to the STO/Si structure.

In yet a further embodiment of the invention, heterostructure **105** may include a second monocrystalline oxide straining layer (not shown) overlying monocrystalline oxide straining layer **104**. This second monocrystalline oxide straining layer may be formed of any of those compounds previously described with reference to layers **102** and **104** in FIGS. 3 and 4. The second monocrystalline oxide straining layer has a crystalline lattice constant which is different from the lattice constant of layer **104** and which may be the same as, or alternatively different from, layer **102**. By the addition of the second monocrystalline oxide straining layer, the offset of the conduction band and valence band at the interface of the substrate and layer **102** may be tailored to the Schottky barrier requirements of a variety of semiconductor device applications. In a similar manner, a third monocrystalline oxide straining layer or more monocrystalline oxide straining layers may be formed overlying the second monocrystalline oxide straining layer to further tailor the conduction band and valence band offsets.

FIG. 6 illustrates schematically, in cross section, a semiconductor device structure **200** fabricated in accordance with a further alternative embodiment of the present invention, wherein semiconductor device structure **200** comprises a component of an MOS device. Structure **200** includes a monocrystalline semiconductor substrate **201**. Monocrystalline semiconductor substrate **201** may be formed of a monocrystalline material such as that comprising layer **101** with reference to FIG. 3. Structure **200** also has a plurality of first monocrystalline oxide straining layers **202** alternating between a plurality of second monocrystalline oxide straining layers **204** which form a strained-layer heterostructure **205**. First monocrystalline oxide straining layers **202** may comprise a monocrystalline oxide material selected for its crystalline (i.e., lattice) compatibility with the underlying substrate and having a first lattice constant. First monocrystalline oxide straining layers **202** may be formed of any of those compounds previously described with reference to layer **102** in FIGS. 3 and 4. In an exemplary embodiment, layer **202** may comprise an alkaline earth metal titanate, such as, for example, barium titanate (BaTiO₃), strontium titanate (SrTiO₃), barium strontium titanate (Sr₂Ba_{1-x}TiO₃), or another suitable oxide material. Second monocrystalline oxide straining layers **204** may be formed of any of those compounds previously described with reference to layer **104** in FIGS. 3 and 4 with a lattice constant that is different from first monocrystalline oxide straining layers **202**. For example, if first monocrystalline oxide straining layers **202** are formed of SrTiO₃, second monocrystalline oxide straining layers may be formed of BaTiO₃, which has a larger crystalline lattice constant than SrTiO₃. In one embodiment, layers **202** are layers of SrTiO₃ having a thickness of up to about 20 angstroms and layers **204** are layers of BaTiO₃ having a thickness of up to 20 angstroms.

It will be appreciated that the materials of first monocrystalline oxide straining layers **202** and second monocrystalline oxide straining layers **204** may be selected to tailor

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the conductive and valence energy band offsets at the interface of strained-layer heterostructure **205** and the underlying substrate to achieve the quality and performance requirements of a variety of semiconductor device applications. For example, second monocrystalline oxide straining layers **204** may be formed of material having a crystalline lattice constant that is less than the crystalline lattice constant of first monocrystalline oxide straining layers **202**.

Alternatively, it will be appreciated that the strained heterostructure overlying the substrate may be formed of any number of layers, wherein each layer has a lattice constant which differs from and/or corresponds to the lattice constants of any of the other layers. The materials of the layers may be selected to produce a desired amount of strain at the interface of the heterostructure and the substrate to engineer the conductive and valence energy band offsets so that Schottky leakage current may be increased or decreased according to the requirements of desired semiconductor device application.

In the foregoing specification, the invention has been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present invention.

Benefits, other advantages, and solutions to problems have been described above with regard to specific embodiments. However, the benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, solution to occur or become more pronounced are not to be constructed as critical, required, or essential features or elements of any or all of the claims. As used, herein, the terms "comprises," "comprising" or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

We claim:

1. A semiconductor structure exhibiting reduced leakage current comprising:

a monocrystalline silicon substrate;

an amorphous oxide material in contact with the monocrystalline silicon substrate; and

a strained-layer heterostructure overlying said substrate, said heterostructure having:

a first layer comprising a first monocrystalline oxide material having a first lattice constant selected from the group consisting of alkaline earth metal titanates, alkaline earth metal zirconates, alkaline earth metal hafnates, alkaline earth metal tantalates, alkaline earth metal ruthenates, alkaline earth metal niobates, alkaline earth metal vanadates, alkaline earth metal tin-based perovskites, lanthanum aluminate, lanthanum scandium oxide, gadolinium oxide and mixtures thereof contacting the amorphous oxide material; and

a second layer comprising a second monocrystalline oxide material overlying said first layer and having a

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second lattice constant, wherein said second lattice constant is different from said first lattice constant, wherein a strain is effected at least at one of an interface of said strained layer heterostructure and said substrate, an interface between said first layer and said second layer, and within said first layer and said second layer, and

wherein said substrate comprises a (001) semiconductor material having an orientation from about 2 degrees to about 6 degrees offset toward the (110) direction.

2. The semiconductor structure of claim **1**, wherein said strained-layer heterostructure further comprises alternating first strained layers and second strained layers, wherein said alternating first and second strained layers overlie said second layer, and wherein said first strained layers comprise said first monocrystalline oxide material and said second strained layers comprise said second monocrystalline oxide material.

3. The semiconductor structure of claim **1**, wherein said first layer has a thickness ranging from approximately one monolayer to approximately 100 angstroms.

4. The semiconductor structure of claim **1**, wherein said second layer has a thickness ranging from approximately one monolayer to approximately 100 angstroms.

5. The semiconductor structure of claim **1**, wherein said second lattice constant is greater than said first lattice constant.

6. The semiconductor structure of claim **1**, wherein said first layer comprises $\text{Sr}_x\text{Ba}_{1-x}\text{TiO}_3$, wherein x ranges from 0 to 1.

7. The semiconductor structure of claim **6**, wherein said second layer comprises $\text{Sr}_y\text{Ba}_{1-y}\text{TiO}_3$, where y is not equal to x .

8. The semiconductor structure of claim **1**, wherein said second layer comprises a monocrystalline oxide material selected from the group consisting of alkaline earth metal titanates, alkaline earth metal zirconates, alkaline earth metal hafnates, alkaline earth metal tantalates, alkaline earth metal ruthenates, alkaline earth metal niobates, alkaline earth metal vanadates, perovskite oxides such as alkaline earth metal tin-based perovskites, lanthanum aluminate, lanthanum scandium oxide, and gadolinium oxide.

9. The semiconductor structure of **1**, wherein said strained-layer heterostructure further comprises a third layer formed of monocrystalline oxide material overlying said second layer and having a third lattice constant, wherein said third lattice constant is different from said second lattice constant.

10. The semiconductor structure of claim **9**, wherein said third lattice constant is approximately equal to said first lattice constant.

11. The semiconductor structure of claim **9**, wherein said third lattice constant is greater than said second lattice constant.

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